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## Housing crisis: Waste glass-stabilized clay for use as fired clay bricks

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# Housing crisis: Waste glass-stabilized clay for use as fired clay bricks

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**Abstract.** Scarce and expensive housing and consumer waste disposal are global challenges in today's world. This study investigated the engineering properties of a clay stabilized with three waste glass sizes (less than 75  $\mu\text{m}$ , greater than 150  $\mu\text{m}$  but less than 75  $\mu\text{m}$ , and less than 300  $\mu\text{m}$  but greater than 150  $\mu\text{m}$ ) for the production of burnt clay bricks for earth building construction. Laboratory tests (sieve analysis, Atterberg limits, specific gravity, and compaction tests) were conducted on the clay soil sample, while firing shrinkage, water absorption, unit weight and compressive strength tests were conducted on the fired clay bricks. The unit weight, firing shrinkage and compressive strength decreased with an increasing particle size of the waste glass in the fired clay bricks, while the fired clay bricks absorbed more water as the particle size of its waste glass content decreased. The use of waste glass with particle sizes less than 75  $\mu\text{m}$  for stabilizing the clay was found to produce fired clay bricks with the highest compressive strength. The compressive strength of the fired clay bricks containing less than 75  $\mu\text{m}$  particle sizes of waste glass was increased by 43.9% when compared with the compressive strength of the fired clay bricks having no waste glass. Consequently, waste glass with particle sizes of less than 75  $\mu\text{m}$  is recommended for use in the production of fired clay bricks. The use of waste glass, which could have been a nuisance to the environment, is a potential way of improving the strength of bricks and making them more affordable bricks and consequently, making housing more affordable.

## 1. Introduction

Globally, many people are burdened by unaffordable, substandard or insecure housing. It has been estimated that about 1.6 billion people in the world are without adequate housing [1], about a billion persons live in slums worldwide [2], and about 150 million people are homeless worldwide [3]. One of the strategies of the UN-Habitat in tackling the global housing crisis is “increasing the supply of affordable housing, especially for the poorest and vulnerable groups” in society.

Depleting natural materials for construction and rising cost of construction materials are some of the causes of housing unaffordability [4,5]. For instance, comparing the June 2017 and June 2018 prices of construction materials in the United States (U. S.) that was presented by the U.S. Bureau of Labor Statistics, it was found that the prices of June 2018 were higher by 9.6 percent [6]. This is why researchers have proposed or explored the use of wastes in modifying indigenous earth building technologies and as cheaper alternatives to conventional building materials [7-11] as a way to minimize urban pollution [12].

This study explores the modification of the engineering characteristics of fired clay bricks produced from the mixture of clay and waste glass as a possible means of providing affordable and stronger

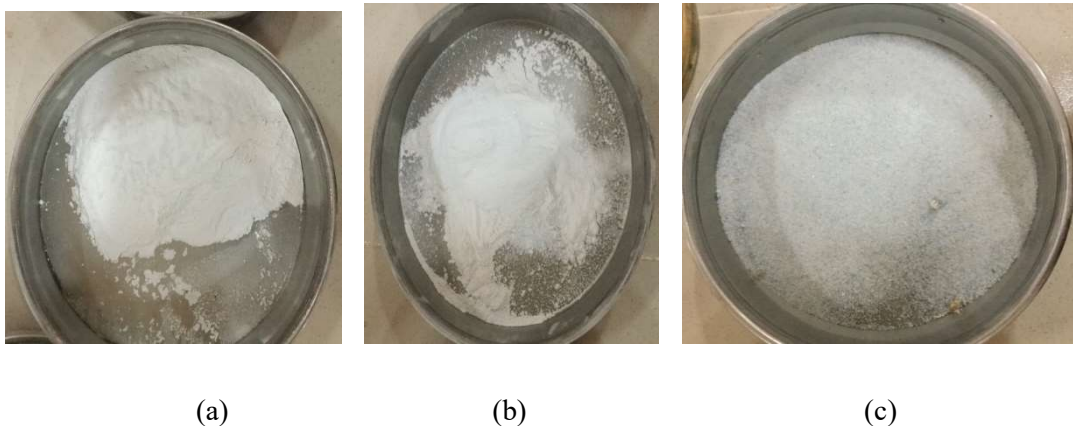


bricks for earth building construction. There is barely little waste glass recycling that is being done in many developing countries. In previous studies, waste glass has been used to replace some portion of cement or aggregates in concrete [13] and in the production of asphalt mixes [14]. This study uniquely explores using waste glass as a construction material for indigenous earth building construction.

## 2. Materials and Methods

The soil used in this study was collected from the Covenant University's stadium construction site, Ota, while the waste glass was obtained from a dump site at Sango-Ota, Ogun State, Nigeria. The soil is brown and felt sticky when wet and rolled between the palms of the hands. The waste glass collected was in the form of broken pieces of glass. The broken pieces of glass were pulverized and fractionated into three different ranges of particle sizes. Samples of the three fractions are shown in Figure 1. One part contained the waste glass particles passing through a sieve (American Society for Testing and Materials (ASTM) Sieve Number 200), with openings of 75  $\mu\text{m}$ ; the second part had its particles passing a sieve of 150  $\mu\text{m}$  openings but having particles greater than the 75  $\mu\text{m}$  sieve openings; while the third part contained waste glass particles passing through a sieve of 300  $\mu\text{m}$  openings but having particles greater than the 150  $\mu\text{m}$  sieve openings.

The soil was characterised by carrying out specific gravity, sieve and hydrometer analyses, Atterberg limits (liquid and plastic limits), and compaction tests in accordance with standards presented in Table 1. Bricks were produced using the soil mixed with 25% of waste glass, while some bricks were produced without waste glass to serve as the bricks for control tests in order to determine the effects of the addition of the waste glass and the effects of the use of the different sizes of the waste glass.



**Figure 1.** The waste glass particle sizes used: (a) <75  $\mu\text{m}$ , (b) <150  $\mu\text{m}$  but >75  $\mu\text{m}$ , and (c) <300  $\mu\text{m}$  but >150  $\mu\text{m}$

**Table 1.** Standards test procedures for tests carried out

Tests	Test procedure in accordance with
Specific gravity	ASTM D854-14 [15]
Particle-size analysis	ASTM D422-63 [16]
Atterberg limits	ASTM D4318-17e1 [17]
Compaction	ASTM D698-12e2 [18]

The dry soil and the waste glass were thoroughly mixed manually for 10 minutes to obtain a homogeneous mixture. After the dry mixing, distilled water of about 10%, (by dry weight of the total weight of the soil or soil-waste-glass mixture) was added to the mixture. The mixing with water is continued until a mixture with uniform consistency is achieved. Rectangular moulds with internal dimensions of 300 mm by 100 mm by 100 mm were used to produce the bricks. The moulded samples were dried under laboratory conditions (23°C) for 24 hours before the moulds were removed. The

dried bricks (Figure 2) were weighed and then subjected to a heat of 1000°C in a furnace, fired to maturity for 1 hour, to make it hard and impervious. After the removal of the bricks from the furnace and after cooling, the bricks were re-weighed and their length measured.

The firing shrinkage, water absorption, unit weight and compressive strength of the fired bricks were determined. The firing shrinkage was determined by calculating the linear shrinkage that resulted from the firing of the bricks using Equation 1.

$$\text{Firing Shrinkage (\%)} = \frac{L_{\text{dried}} - L_{\text{fired}}}{L_{\text{dried}}} \times 100 \quad (1)$$

where  $L_{\text{dried}}$  = Length of dried brick sample

$L_{\text{fired}}$  = Length of fired brick sample



**Figure 2.** Some of the dried bricks before being fired in the furnace

The bulk unit weight was calculated by dividing the weight of the fired brick by its volume. To determine the water absorption, the fired brick with a known mass ( $W_d$ ) was placed in a pond of water for 24 hours. After 24 hours, the bricks were removed and excess water was allowed to drain. The saturated bricks were weighed and their weights were recorded as  $W_s$ . The water absorption (%) was calculated using Equation 2. Compression testing machine was used to determine the load that causes failure of the brick and this was used to calculate the compressive strength of the bricks.

$$\text{Water absorption (\%)} = \frac{W_s - W_d}{W_d} \times 100 \quad (2)$$

### 3. Results and Discussion

#### 3.1. Index properties of the soil

The specific gravity of the soil was found to be 2.73. From the sieve and hydrometer analyses, the particle-sizes of the soil were analyzed as presented in Figure 3. After wet sieving of the soil using the sieve with 75 µm openings, 52% of the soil sample passed through the sieve and can be described as fine-grained. Hydrometer analysis was carried out on the 52% fraction to determine their particle-size distribution (Figure 3). The clay-sized fraction of the soil was determined to be 37.6%, the silt fraction is 14.4%, while the remaining 48% of the soil is sand. The soil's liquid limit was determined to be 43%, while its plastic limit is 25.6%. Consequently, the plasticity index is 17.4%. The soil can be classified as sandy clay of low plasticity (CL), according to the Unified Soil Classification System (USCS) (Figure 4). The activity of the soil was calculated to be 0.46, indicating that it has a low water absorption capacity. Based on the activity, the soil can be classified as inactive and its predominant clay mineral is likely to be kaolinite [19].

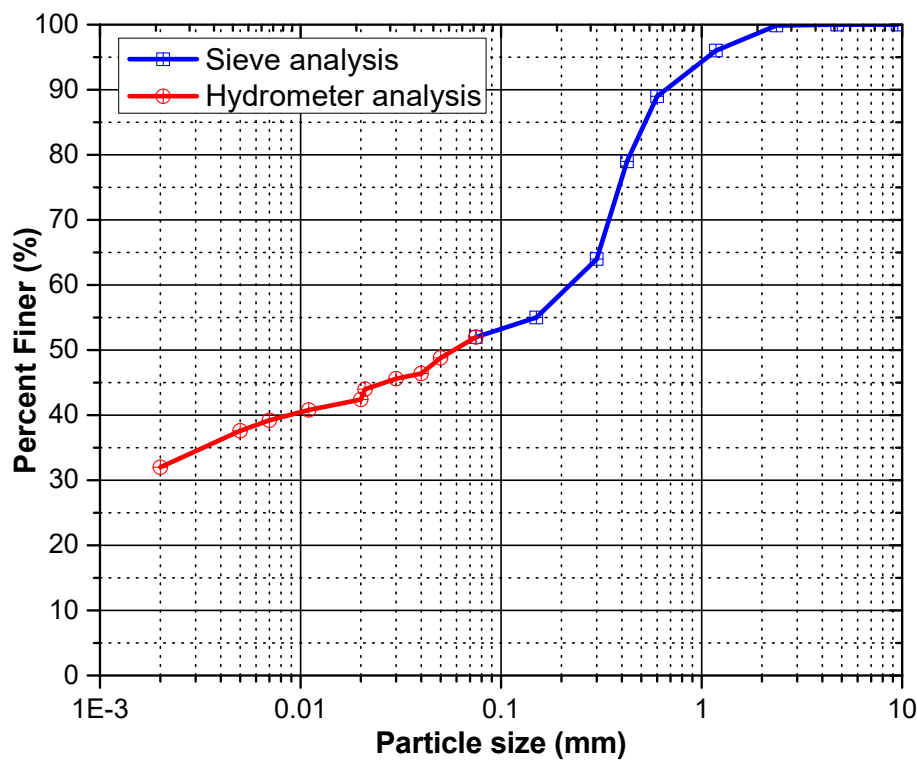


Figure 3. Particle size distribution for the soil

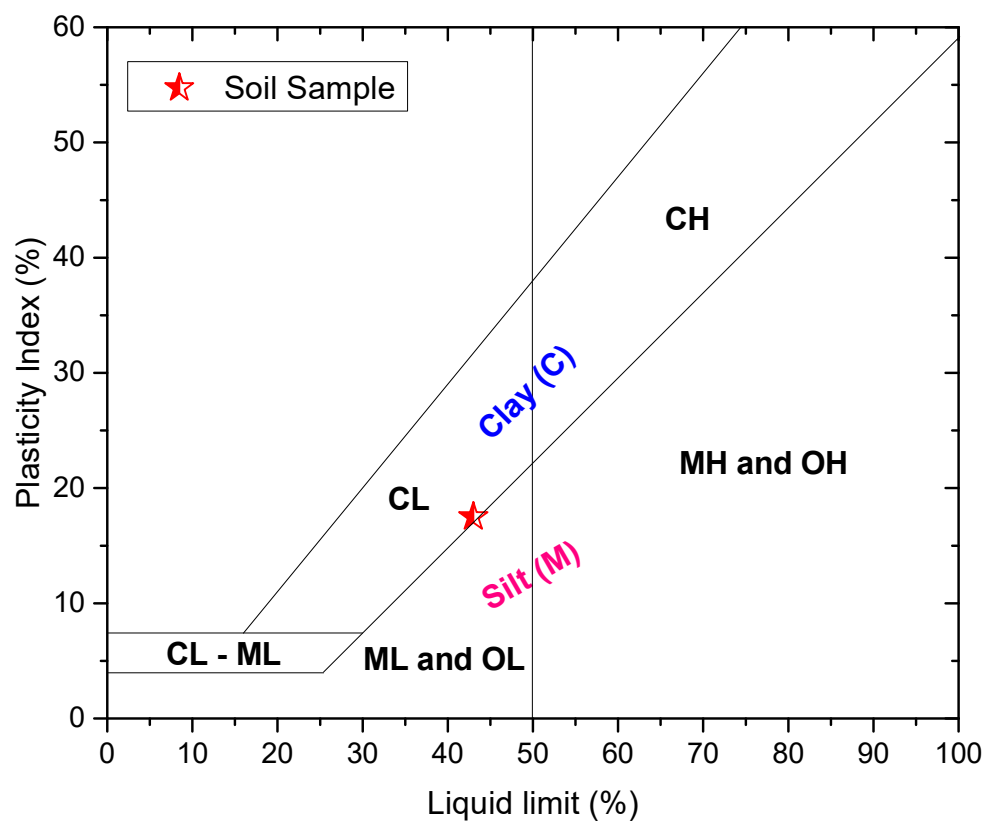
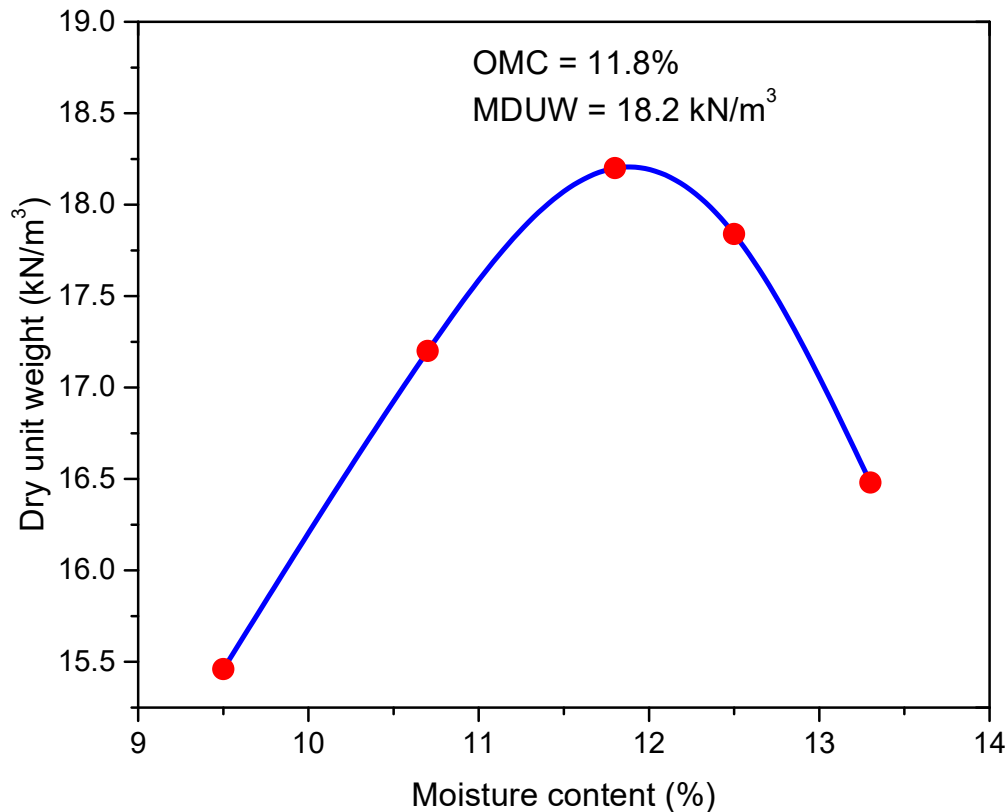


Figure 4. USCS Plasticity chart for the soil

The compaction curve shown in Figure 5 describes how the dry unit weights of the soil relates with its moisture contents. From the compaction curve, the maximum dry unit weight (MDUW) and the

optimum moisture content (OMC) for the soil were determined. The MDUW was determined as 18.2 kN/m<sup>3</sup>, while the OMC is 11.8%.

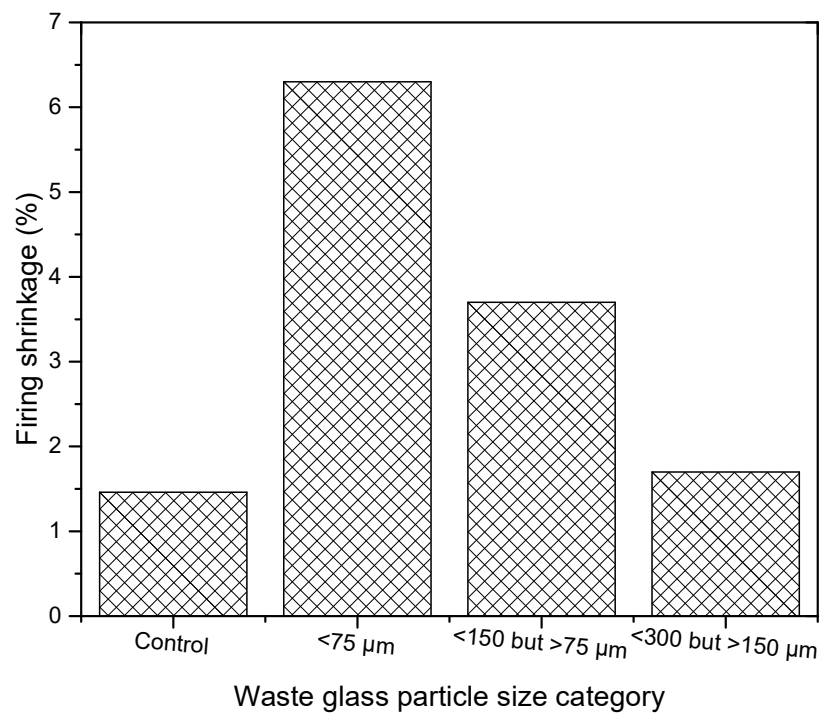
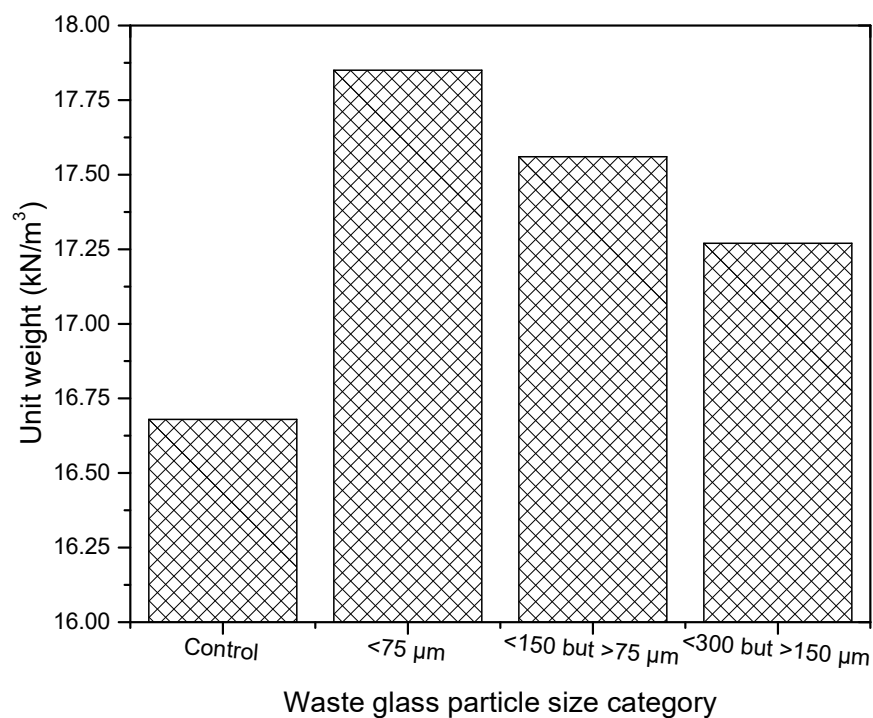


**Figure 5.** Compaction characteristics of the soil

### 3.2. Properties of the bricks

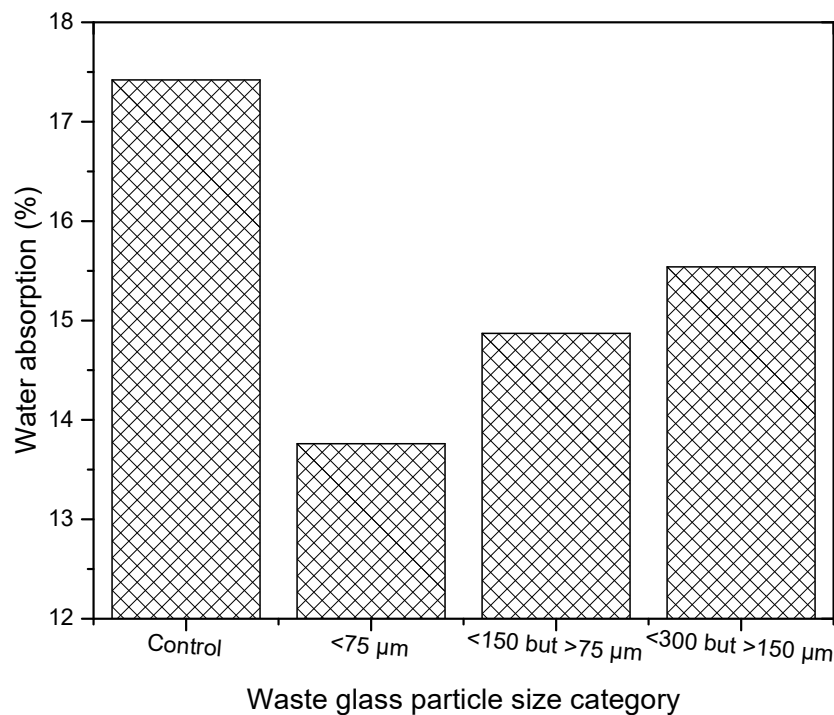
The firing of the clay bricks resulted in the progressive shrinkage of the bricks as moisture in the bricks vaporizes. This continued until a maximum shrinkage, which is called the firing shrinkage, was achieved. The average values of the firing shrinkage for each of the categories of bricks are illustrated in Figure 6. From Figure 6, the clay bricks without waste glass in them had the least firing shrinkage. Also, the firing shrinkage decreased with increasing particle sizes of the waste glass content in the bricks. Weng et al. [20] reported that in accordance with Chinese National Standards (CNS) [21], the firing shrinkage of clay bricks should not exceed 8% in order to obtain good quality bricks exhibiting desirable mechanical properties. For the particle sizes of the waste glass content in the bricks studied, the firing shrinkage was less than 8%. The shrinkage values for all samples are within safe limits for construction as stated in ASTM C326 [22]. Based on firing shrinkage, the most preferred bricks containing waste glass are those having a waste glass of particles passing through a sieve of 300  $\mu\text{m}$  openings but greater than the 150  $\mu\text{m}$  sieve openings.

The bulk unit weight of the bricks was obtained by dividing the weight of the fired bricks with the volume of the bricks. The average values of the bulk unit weight are presented in Figure 7. From Figure 7, as the waste glass particle sizes increased, the bulk unit weight of the bricks decreased. Based on the bulk unit weight, the bricks with the densest packing are those having a waste glass of particles passing through a sieve of 75  $\mu\text{m}$  openings. When the bulk unit weight of fired bricks increases, it is typically expected that it leads to a decrease in its water absorption and an increase in its strength.

**Figure 6.** Firing shrinkage of the bricks**Figure 7.** Unit weight of the bricks

The absorption of water by the fired bricks describes the amount of water that it can assimilate in relation to its weight. This property is important because it can affect the deformation and strength

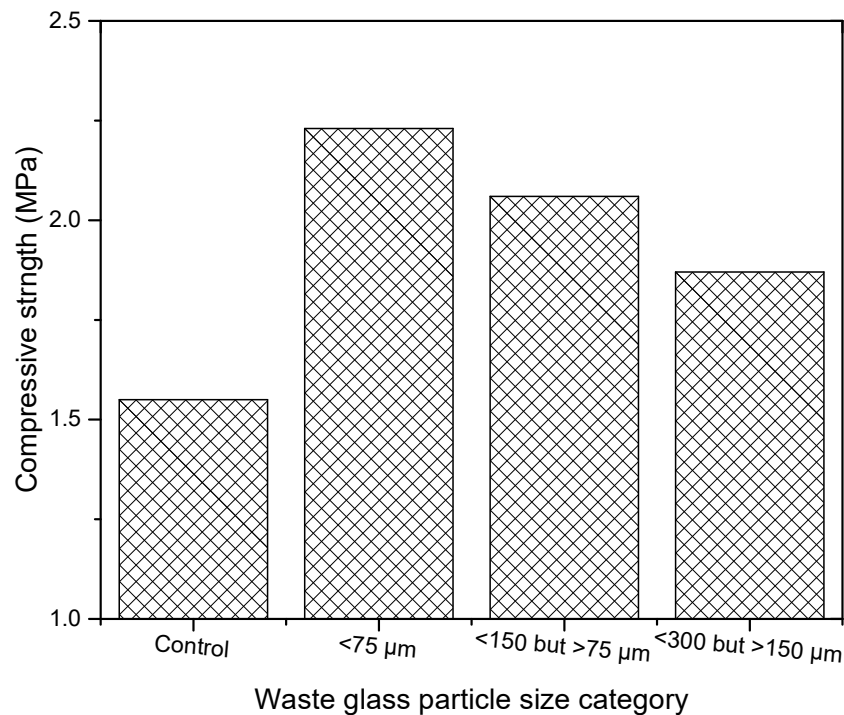
properties of the bricks. Figure 8 illustrates the variation of water absorption by the bricks. The reference/control bricks had greater water absorption than the bricks containing waste glass. Of the bricks containing waste glass, the bricks having a waste glass of particle sizes passing than 75  $\mu\text{m}$  sieve openings had the least water absorption. According to CNS [21], as reported by Weng et al. [20], the water absorption by bricks should not exceed 15%. As expected, the relationship between the bulk unit weight of the bricks and the particle sizes of the waste glass contained in them is inverse of the relationship between the water absorption by the bricks and particle sizes of its waste glass content.



**Figure 8.** Water absorption by the bricks

The ability of a brick to withstand load subjected to it is one of its most important mechanical properties. Figure 9 presents the variation of the average values of the compressive strength of the bricks with their waste glass content. The inclusion of waste glass in making the fired bricks, generally, increased the compressive strength of the fired bricks. Figure 9 shows that the average compressive strength of the fired bricks increased with a decrease in the particle sizes of its waste glass content. Though the compressive strengths of the fired bricks were generally low, the clay bricks containing waste glass of particle sizes less than 75  $\mu\text{m}$  had a compressive strength that was more improved by 43.9%, when compared with the bricks without waste glass.





**Figure 9.** Compressive strength of the bricks

#### 4. Conclusions

This research work investigated the engineering properties of a clay stabilized with three sizes (less than 75  $\mu\text{m}$ , greater than 150  $\mu\text{m}$  but less than 75  $\mu\text{m}$ , and less than 300  $\mu\text{m}$  but greater than 150  $\mu\text{m}$ ) of waste glass for the production of burnt clay bricks for earth building construction. The soil was classified as a sandy clay of low plasticity (CL), according to the Unified Soil Classification System (USCS). The sandy clay and waste glass samples were used to produce bricks that were tested for their firing shrinkage, bulk unit weight, water absorption and compressive strength. The firing shrinkage, bulk unit weight and compressive strength of the bricks decreased with the increasing particle sizes of the waste glass content in the bricks, while the water absorption increased with increasing particle sizes of the waste glass content in the bricks. Generally, a waste glass of particle sizes less than 75  $\mu\text{m}$  is recommended for use in improving the properties of bricks made with clay of similar geotechnical properties as those studied. For the universal utilization of waste glass fired clay bricks, future research works on their durability, cost and life-cycle assessment are recommended.

The overall significance of these findings is that waste glass, which is a consumer waste whose improper disposal is causing environmental nuisance, can become an affordable means for providing stronger clay bricks and consequently, affordable housing.

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